Supplemental materials

Methods

Partial occlusion

The amblyopic brain relies primarily on signals from the stronger dominant eye and suppresses signals from the weaker affected eye with reduced vision. To remove this obstacle to binocular vision, we asked our participants to wear a Bangerter blur filter (Ryser Optik, St. Gallen, Switzerland) over the sound eye in order to reduce its crowded visual acuity to roughly 60%, or two lines on a standard logMAR letter chart (National Vision Research Institute of Australia, 1978), worse than that of the fellow amblyopic eye. Our previous work with neurotypical observers suggests that placing this type of filter before one eye preserves stereopsis at low spatial frequencies[3]. Throughout the course of the video game intervention, the Bangerter filter was adjusted as visual acuity improved.

Participants

Twenty-one adults with amblyopia participated (age range, 19-79 years; mean age, 34.5 ± [SD] 13.5 years; male, 8; female, 13). Inclusion criteria included: (1) all forms of amblyopia, including strabismic, anisometropic, refractive, deprivation, and astigmatism-related amblyopia; and (2) interocular visual acuity difference of 0.1 logMAR or more. Exclusion criteria included any pathological eye conditions. The maculae of all participants were assessed as normal, and they all had clear ocular media. All our participants, except SAN1 who had nystagmus, had normal vision in the preferred eye. Their visual characteristics are summarized in Table S1 (sample size, 21: non-strabismic amblyopia, 11; strabismic amblyopia, 10).

General procedures

In the main experiment, participants were required to play stereoscopic 3D video games for a total of 40 hours, 2 hours per session, over 4-6 weeks in our research laboratory. First-person shooter action video games were used, such as Killzone 3 (Sony Computer Entertainment), SOCOM 4: U.S. Navy Seals (Sony Computer Entertainment), Ratchet & Clank (Sony Computer Entertainment), and Crysis 3 (Electronic Arts). The stronger dominant eye was blurred with Bangerter foils (Ryser Optik, St. Gallen, Switzerland) to a level of roughly 0.2 logMAR worse than crowded visual acuity in the amblyopic eye. Note that the Bangerter foils provided to our participants were based on our clinical measurements, not the filter designation provided by the manufacturer. The filters were applied onto a plano lens which was then taped to a trial frame so that each individual participant used the same prescribed blurring lens in all gaming sessions. A 32-inch Panasonic active 3D television (model, TC-L32DT30; resolution, 1920 x 1080; refresh rate, 120 Hz) and a pair of active liquid crystal shutter glasses (model, TY-EW3D3MU; Panasonic, Japan) were used to display stereoscopic game content with a Sony PlayStation 3 system (Sony Interactive Entertainment, Japan). The viewing distance was 1 m, but participants were allowed to view the screen at a shorter distance, normally not less than 50cm, if they found it too blurry.

We measured visual acuity (Fig 1A, inset) and stereoacuity (Fig 1D, inset) in pre-training and post-training assessment sessions. All visual stimuli were displayed on a 21-inch flat Sony F520 monitor screen at 1800 x 1440 resolution and 85 Hz refresh rate. Participants wore full optical correction for all training and assessment sessions. Appropriate near addition was provided for those participants with presbyopia.

Stereoacuity

An experimental set-up similar to that in our recent studies[3] was used to measure stereoacuity. The visual stimulus was comprised of two horizontally separated black squares (Fig 1D). At the center of each square, there was a target Gabor patch surrounded by four reference Gabor patches. A custom-built 4-mirror haploscope was used to present a half monitor screen to each eye (i.e. the left square to the left eye and the right square to the right eye). Binocular disparity was introduced by shifting the two target patches, one in each square, in opposite horizontal directions. To eliminate any potential monocular cues, the position and carrier phase of each target and reference Gabor patch were randomly jittered based on a uniform distribution (vertical and horizontal position range, ±200-1600 arcsec; phase range, 0-360^o). The mean luminance of the stimuli was 55 cd/m^2 and the contrast of each Gabor patch was 99%. The visual task was to determine the stereoscopic depth of the target Gabor (in front or behind) relative to the four adjacent reference Gabor patches. A trial-by-trial audio feedback was provided for each response.

For each trial, the amount of binocular disparity between the target Gabors presented to each eye was determined by two interleaved adaptive staircases to track the threshold: one was for crossed disparity (the target patch appears in front of the reference patches), while the other was for uncrossed disparity (the target patch appears behind the reference patches). The trials were divided into triplets: three correct responses decreased the disparity magnitude by one unit step, two correct responses left the disparity unchanged, and only one or no correct response increased the disparity by two unit steps. The starting disparity was roughly two times the individual observer's threshold disparity (or two-third of the maximum measurable disparity, see below, for the stereo-blind participants), and the step size was roughly one-third to half of the threshold disparity. Stereoacuity was defined as the disparity at the 84% correct response rates (*d*'=1) obtained by fitting a Probit function. Each run consisted of 160 response trials: 75 trials of crossed disparity, 75 trials of uncrossed disparity, and 10 trials with zero disparity.

The stimulus spatial scale was manipulated by adjusting the physical size on the screen and varying the viewing distance: 50 cm (V1), 1 m (V2) or 2 m (V5-V15). For V5 stimuli viewed at 2 m, the envelope size was 7 arcmin, the reference-target center-to-center distance was 48 arcmin when positional jittering was disabled, the 'E' size was 25 x 25 arcmin, and the square frame was 197.3 arcmin. The inter-pixel distance was 20 arcsec at a viewing distance of 2 m (50 cm, 80 arcsec); sub-pixel accuracy was achieved by contrast manipulation. The maximum measurable disparities (crossed or uncrossed) were 8000, 4000, 2000, and 1000 arcsec for V1, V2, V5 and V10, respectively.

Table S1. Visual profile of amblyopia. Abbreviations: (1) Type of amblyopia. S, strabismic amblyopia; A, anisometropic amblyopia; R, refractive amblyopia; M, astigmatism-related amblyopia; C, congenital cataract; N, nystagmus. (2) Cover test. ExoT, exotopia; EsoT, esotopia; HyperT, hypertropia; ExoP, exophoria; EsoP, esophoria; NMD, no movement detected.

#	Group	Observer	Gender	Age (yrs)	Type	Eye	Refractive error	Visual acuity - Crowded [isolated] (Snellen)	Cover test (at 6m)
1	NS	MBL	M	28.3	A	R L	-2.50 +0.75	20/12.5 $20/80^{-2}$ ($20/63^{-2}$)	NMD
2	NS	JTL	M	36.2	A	R L	-1.50/-0.25x160 +0.75/-0.50x165	$20/16^{+1}$ $20/40^{-2}$ ($20/40^{+2}$)	4^{Δ} ExoP
3	NS	TXY	F	22.7	A	R L	-2.00/-1.25x15 -2.25	$20/40^{+1}$ ($20/32^{-2}$) $20/16^{+2}$	NMD
4	NS	VXH	F	20.6	A	R L	+2.25/-1.00x120 -0.25	$20/40^{+2}$ ($20/40^{+2}$) $20/16^{+2}$	NMD
5	NS	KRL	F	20.6	A	R L	+3.50/-0.25x165 plano/-0.75x20	$20/32^{-1}$ ($20/25^{-2}$) $20/12.5^{-2}$	4^{Δ} EsoP
6	NS	SCC	M	49.3	A	R L	+0.25 +1.75	$20/16^{-1}$ $20/25^{-1}$ ($20/25^{-1}$)	NMD
7	NS	EEY	F	20.3	A	R L	-0.25/-0.25x175 +5.50/-1.50x60	$20/16^{+2}$ $20/25^{+2}$ ($20/25^{+2}$)	4^{Δ} ExoP
8	NS	PKT	F	19.3	A	R L	+3.25/-0.25x135 +1.25/-0.50x140	$20/25^{+2}$ ($20/25^{+2}$) $20/12.5^{+1}$	NMD
9	NS	MXB	F	38.4	A	R L	+6.25/-1.00x110 +5.25/-1.00x75	$20/20^{-1}$ ($20/20^{+1}$) $20/16^{+2}$	5^{Δ} EsoP
10	NS	JBS	F	25.6	C	R L	-7.00/-1.75x180 (IOL) plano	$20/63^{+2}$ ($20/50^{-1}$) $20/16^{+2}$	5^{Δ} ExoP
11	NS	YXC	F	48.1	R, M	R L	-14.75/-3.50x75 -2.25/-1.75x160	20/40 ($20/40^{-1}$) $20/16^{-2}$	L 4^{Δ} HyperP
12	S	RCS	M	79.1	S	R L	+1.75/-2.75x5 +1.50/-1.50x160	$20/16^{+2}$ $20/80^{-1}$ ($20/40^{-2}$)	L 2^{Δ} EsoT, L 2^{Δ} HyperT
13	S	CAA	M	28.0	S	R L	+1.25/-0.75x45 +0.75/-0.50x160	20/20 $20/63^{+1}$ ($20/32^{-1}$)	L 6^{Δ} ExoT, R 1^{Δ} HyperT (Intermittent)
14	S	DJS	F	33.8	S	R L	-1.25 -4.00	$20/50^{+2}$ ($20/32^{+2}$) $20/16^{-1}$	R 12^{Δ} ExoT
15	S	MSL	M	42.8	S	R L	+0.25/-0.50x50 -0.25/-0.25x130	$20/10^{-2}$ $20/40^{-2}$ ($20/32^{+2}$)	L 5^{Δ} EsoT
16	S	HMK	F	36.3	S	R L	+0.25 +0.25	$20/40^{-1}$ ($20/32^{-2}$) $20/16^{+1}$	R 6^{Δ} EsoT
17	S	JED	M	40.4	S	R L	+0.25 +0.50/-0.25x180	20/12.5 $20/32^{+2}$ (20/20)	L 8^{Δ} EsoT
18	S	RXS	F	38.4	S	R L	-4.50/-0.75x20 +0.50/-0.75x165	$20/25^{-1}$ ($20/20^{-2}$) $20/16^{-1}$	R 3^{Δ} EsoT, L 4^{Δ} HyperT
19	S	VHC	F	29.9	S, A	R L	+2.75/-1.00x180 +0.75/-0.50x175	$20/160^{+2}$ ($20/125^{+2}$) $20/16^{+2}$	R 12^{Δ} ExoT
20	S	QXD	M	33.2	S, A	R L	-1.00/-0.50x175 +2.25/-0.75x175	$20/12^{-2}$ $20/32^{-1}$ ($20/32^{+1}$)	L 4^{Δ} ExoT (Intermittent)
21	S	SLO	F	33.4	S, A, N	R L	+3.50 +1.50	$20/25^{-2}$ ($20/25^{+2}$) $20/25^{+2}$ ($20/20^{+1}$)	R 8^{Δ} ExoT, R 6^{Δ} HyperT, latent nystagmus*